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CONTROL OF DRINKING WATER QUALITY IN OPEN DISTRIBUTION RESERVOIRS

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CONTROL OF DRINKING WATER QUALITY IN OPEN DISTRIBUTION RESERVOIRS

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The East Bay Municipal Utility District is the principal water supply agency for the ten California cities of Alameda, Albany, Berkeley, El Cerrito, Emeryville, Oakland, Piedmont, Richmond, San Leandro, San Pablo, and a large unincorporated area located on the east side of the San Francisco Bay.

The District now serves water to nearly one million people living in an area of more than 200 square miles. During the past fiscal year, 1951-52 , the average water consumption was 112.1 million gallons per day.

Quality of Treated Water Leaving District Filter Plants

All of the water supplied by the District is treated at modern filtration plants before delivery to the consumers. In general, the treatment given the water includes aeration, coagulation with alum followed by sedimentation, lime treatment for pH adjustment and corrosion control, filtration through rapid sand filter beds, and chlorination. These treatment processes are varied as required to produce satisfactory treated water, and at times carbon is used for taste and odor control. The average treated water which leaves the filter plants has a turbidity of less than 0.5 ppm, is free from tastes and odors, and contains no algae or crustacea. The average coliform count of the treated water leaving the filter plants is 0.0 per cent of the 10 ml portions examined. Since the Drinking Water Standards of the United States Public Health Service state in part that the turbidity of a treated water to be used for drinking purposes shall not be over 10 ppm, and that not more than 10 per cent of the 10 ml portions examined shall be positive for coliform organisms, it is seen that the water which is delivered to the distribution system from the filter plants operated by the District is of an extremely high quality.

Brief Description of Water Distribution System of the District

The topography of the area served by the District is such that the District is required to deliver water from sea level up to an elevation of 1,500 feet above sea level. In order to supply an ample amount of water at an adequate pressure to the approximately one million people located within the 200 square mile service area, the distribution system is divided into 94 separate pressure zones. At the present time there are 92 distribution reservoirs and tanks, 70 pumping plants, and 75 pressure regulator installations in the distribution system.

Seven of the largest treated water distribution reservoirs, representing 80 per cent of the total storage in the distribution system, are at present uncovered. It is the purpose of this paper to discuss some of the problems involved in maintaining the quality of the water which is stored in these open distribution reservoirs.

Description of Open Reservoirs and Methods of Operation

The capacity and average depth of each of the seven open distribution reservoirs are shown in this table:

Name of Reservoir	Elevation of Spillway	At Spillway Elevation		
		Capacity in Million Gallons	Surface Area in Acres	Maximum Depth in Feet
Central	201.7	158.8	19.4	47.7
Summit	816.3	37.0	6.9	19.7
Seneca	300.0	29.7	4.9	26.7
Berryman	506.0	23.2	3.9	34.0
Piedmont No. 2	600.0	20.8	3.5	43.0
Piedmont No. 1	772.0	17.6	2.7	30.0
Claremont	301.0	8.1	1.5	21.0

The open distribution reservoirs of the District are filled either by gravity flow from the filter plants, or by pumping from the distribution system. Since these gravity lines and pump lines are part of the distribution system, the water which reaches the distribution reservoirs from the filter plants by flowing through a network of distribution mains should have the same high quality as when it left the filter plant. This is assuming, of course, that there are no cross-connections between District water mains and private sources of water, and that all new and repaired water mains are properly chlorinated and flushed before being put into service. However, as soon as the water enters an open distribution reservoir where it is exposed to the elements, it starts to deteriorate in quality.

Since the water which leaves the open distribution reservoirs of the District goes directly to the consumers without further treatment, it is important that the water in these reservoirs be maintained in a safe and palatable condition at all times. It is, therefore, necessary that a careful control be maintained of the physical, chemical, biological, and bacteriological characteristics of the water.

Control of Microscopic Organisms

Experience has shown that microscopic organisms or plankton, such as algae, protozoa, rotifera, and crustacea, may develop in treated water almost as soon as it reaches an open distribution reservoir, even though the treated water entering the reservoir contains more of these organisms. Since these organisms are so universal in nature, it is impossible to keep them from reaching an open reservoir.

Microscopic organisms, such as algae, protozoa, rotifera, and crustacea, are objectionable in a treated water for the following reasons:

(a) Water containing these organisms may develop a definite taste and odor.

(b) Water containing these organisms may have a definite color.

(c) Water containing visible organisms, such as crustacea, is unsatisfactory to the consumers.
(d) Water containing microscopic organisms may not be satisfactory for certain industrial uses.

A considerable amount of organic material is added to water as a result of plankton growths. There is no positive evidence that this organic material affects the health of the people consuming the water, but some theories have been advanced that plankton are responsible for certain unexplained gastrointestinal epidemics which have occurred in some cities. For these reasons, the District has established a rigorous program for the control of microscopic organisms in open distribution reservoirs.

1. Collecting Plankton Samples

Once each week a plankton net catch is taken from each reservoir. The plankton catch is delivered to the Laboratory where the Sanitary Chemists examine the catch under a microscope. The various types of organisms are identified, and a report is sent to the Sanitary Engineers who determine whether treatment of the water is required.

2. Transparency Tests

Once each week a white plate transparency test is made by lowering an 8-inch white enamel plate into the water.

The transparency test indicates whether there has been any change in the amount of color or suspended matter in the water. A decided change in the transparency of the water may be due to an increase in algae growths or turbidity, and serves as a warning signal that some change has taken place in the quality of the water which calls for an immediate investigation.

3. Dissolved Oxygen Determinations

Once each week a dissolved oxygen test is made of the top and bottom water in the reservoir. Water stored in an open reservoir dissolves oxygen from the air, and, in addition, living algae in the water produce oxygen in the water. On the other hand, dead algae, which settle to the bottom of a reservoir, soon start to decompose due to the presence of certain types of bacteria which utilize organic materials as a food supply and produce by-products which may give a taste and odor to the bottom water. As the process of decomposition continues in the bottom of the reservoir, the oxygen decreases and finally disappears and the water becomes stagnant. Therefore, the amount of dissolved oxygen in the water in an open distribution reservoir at any time is some indication of the amount of living and dead algae in the water.

4. Treatments with Copper Sulphate

In general, the open distribution reservoirs operated by the District are treated with copper sulphate every two weeks between March 1 and November 1, and every three weeks from November 1 to March 1, in order to prevent the development of microscopic organisms in these treated waters. The treatments are more frequent during the warmer months of the year since most types of algae multiply more rapidly during these months in the reservoirs of the District.

Samples of water are collected from each distribution reservoir before and after each treatment with copper sulphate for delivery to the Laboratory where tests are made to determine the quantity of residual copper in the

water. An attempt is made to keep the copper content of the water below 0.2 ppm at all times. If the copper content is above 0.15 ppm the day before the scheduled treatment date, the treatment of the reservoir is postponed for one week at which time another test is made of the copper residual. Normally, the copper residual remains in the water for only a few days following the treatment.

The copper sulphate ($CuSO_4 \cdot 5H_2O$) dosage applied to open distribution reservoirs usually ranges from 2.5 to 5.0 pounds per million gallons of water in the reservoirs, depending upon the amount of copper in the water at the time of the treatment. A dosage of 4 pounds per million gallons is equal to about 0.1 ppm of copper. Since the copper content of the water in the District distribution reservoirs normally does not exceed 0.2 ppm, it is well within the allowable limit of 3.0 ppm established by Drinking Water Standards of the United States Public Health Service.

In treating the distribution reservoirs with copper sulphate, a rowboat equipped with an outboard motor is used. In general, the reservoirs are treated by suspending burlap bags containing about 25 pounds of copper sulphate over the sides of the boat, and guiding the boat back and forth across the reservoir in lanes about 25 feet apart. In treating the shallower sections, one bag is suspended just below the surface of the water. In areas where the water is at least 10 feet deep, an additional bag is tied to a rope about 10 feet long. In this way it is possible to get the copper solution directly into the deeper parts of the reservoir.

5. Results of Methods Used to Control Microscopic Organisms

A few heavy growths of nannoplankton (dwarf plankton) have occurred in distribution reservoirs of the District, particularly Central and Seneca Reservoirs, in spite of the copper sulphate treatment. These plankton are so small that they cannot be collected by means of a regular plankton net, but samples of water have been centrifuged and found to contain large quantities of these organisms. These nannoplankton are often of a bacterial size and their presence in the water is first indicated by a decrease in the transparency of the water. Heavy growths of these plankton seem to occur during the winter months. One growth in Central Reservoir reduced the transparency to 4.0 feet, and another growth in Seneca Reservoir reduced the transparency to 3.5 feet. These transparencies were equivalent to a turbidity of about 15 to 20 ppm, but since the plankton growths were confined to the upper stratum of the water in the reservoir and since water was being drawn from a lower stratum, very little of the water containing large quantities of plankton entered the distribution mains directly. Copper sulphate treatments up to 8 pounds per million gallons of water appeared to have little effect upon the nannoplankton. It is believed now that these plankton are the principal cause of reduced transparency in the open distribution reservoirs.

On a few occasions during the past two decades some crustacea and rotifera have been present in the distribution reservoirs in spite of copper sulphate treatments, but not in sufficient quantities to cause complaints by the consumers.

It is known that copper sulphate is less effective in eliminating algae when applied to cold water than when applied to warm water. Tests are now being conducted to determine whether copper sulphate treatments greater than 8 pounds per million gallons will eliminate algae growths during the winter months when the water is colder.

The data presented in Table No. 1 summarize the biological data for open reservoirs for a typical year. It will be noted that the average total plankton catch is only a trace. Also, the bottom dissolved oxygen does not drop below 90 per cent saturation, indicating that very little decomposition of organic material takes place. It will be noted that the transparency does not drop below 7.0 feet during a typical year, although, as noted above, it has dropped to as low as 3.5 feet. No data are presented for Seneca Reservoir since this reservoir has not been in service long enough to establish typical data.

TABLE NO. 1
RESERVOIR BIOLOGICAL DATA FOR A TYPICAL YEAR

Reservoir	Surface Temperature in Degrees F°			Bottom Dissolved Oxygen in % Saturation		Plankton Catch in Mi. per Cubic Meter	Transparency in Feet of Water		
	Avg.	Max.	Min.	Max.	Min.	Max.	Avg.	Max.	Min.
Central	59	70	46	104	93	Trace	16.0	23.0	12.0
Summit	60	73	42	110	94	Trace	14.0	18.5	7.0
Berryman	63	74	49	107	95	Trace	16.0	23.0	8.0
Piedmont No. 2	64	75	46	113	90	Trace	15.0	19.0	10.0
Piedmont No. 1	61	75	46	105	90	Trace	17.0	28.5	10.0
Claremont	63	76	46	110	91	Trace	14.0	18.0	8.5

Bacteriological and Chemical Control

Twice each week samples of water are collected from each open distribution reservoir in sterile sample bottles. These samples are taken to the Laboratory within a few hours after collection where bacteriological tests are made.

Table No. 2 summarizes data on the coliform organisms in the open distribution reservoirs for the 6 years from July 1946 through June 1952, expressed as per cent of 10 ml portions positive for coliform organisms, using brilliant green lactose bile broth. While examining the data presented in this table, it should be kept in mind that the United States Public Health Service Drinking Water Standards state that in a water satisfactory for human consumption not more than 10 per cent of the 10 ml portions examined each month shall show the presence of organisms of the coliform group.

The data in Table No. 2 show the number of months during the 6 years when: (a) Coliform organisms were present in each reservoir, and (b) coliform organisms in the 10 ml portions examined exceed 10 per cent.

TABLE NO. 2
SIX YEARS - JULY 1946 THROUGH JUNE 1952

Reservoir	Coliform Organisms Present		Coliform Organisms Exceeded 10 Per Cent	
	Number of Months	Per Cent of Months	Number of Months	Per Cent of Months
Central	9	12.5	0	0.0
Summit	9	12.5	0	0.0
Berryman	17	23.6	0	0.0
Piedmont No. 2	17	23.6	1	1.4
Piedmont No. 1	17	23.6	0	0.0
Claremont	21	29.2	1	1.4

The above tabulation shows that coliform organisms were present in the open distribution reservoirs from 12.5 to 29.2 per cent of the time, but there were only 2 months during the 6 years that the coliform count exceeded the 10 per cent limit established by the Drinking Water Standards. The coliform count of Piedmont No. 2 and Claremont Reservoirs exceeded the 10 per cent limit during only one month, while the coliform count of the other four reservoirs always remained below the 10 per cent limit.

Because of the low bacterial count of the water in the open reservoirs, and since the per cent of coliforms has exceeded 10 per cent on so few occasions, the District has not installed chlorinators on the outlet lines from the distribution reservoirs. It was necessary, however, on the two occasions when the per cent of 10 ml portions positive for coliforms exceeded 10 per cent, to treat the water in the two reservoirs with a hypochlorite solution.

It should be noted that samples taken from the distribution systems served by these reservoirs seldom show the presence of coliform organisms and always meet the Drinking Water Standards, indicating that most of the coliform organisms are near the surface of the reservoir.

As a rule, bacteriological tests which are made using eosin methylene blue agar as a check on the brilliant green lactose bile broth show that the bacteria found in the open reservoirs of the District are mixtures of A.Aerogenes and E.Coli. However, at times the bacteria are almost all E.Coli, and at other times nearly all A.Aerogenes. The A.Aerogenes bacteria which are typical of bacteria found in the soil and on plants are probably carried into the reservoir by the wind. The E.Coli bacteria are undoubtedly of bird and animal origin rather than human origin.

The average yearly coliform content of the water in the open reservoirs varied from 0.0 to 3.0 per cent. During these same six years the average monthly as well as the average yearly, coliform content of the treated waters leaving the filter plants averaged 0.0 per cent. It can be concluded from these facts that the bacterial content of the water stored in the open distribution reservoirs during the past six years was considerably higher than that of the filtered water, but at the same time it must be noted that the water in four of the reservoirs met the Drinking Water Standards at all times, and the water in the other two reservoirs failed to meet the standards only during one month of the six-year period.

It should be mentioned here that the District operates one partially covered distribution reservoir, which has always shown higher bacterial

counts than any of the open reservoirs. This reservoir is covered with boards spaced about one-half of an inch apart. District experience, therefore, indicates that a reservoir covered with loose boards is less desirable than an open reservoir from the standpoint of the bacterial quality of the water.

It is amazing that the average quality of the water in the open distribution reservoirs of the District remains so high. The fact that the pH of the water entering the reservoirs is relatively high, ranging from 8.0 to 9.2, may help to prevent the growth of bacteria. Although a chlorine residual is not maintained in the top waters of the distribution reservoirs, a large portion of the water entering these reservoirs does have a small chlorine residual, usually less than 0.1 ppm. This small chlorine residual undoubtedly plays some part in keeping the bacterial count of the water at a low level. It is also possible the bactericidal action of sunlight helps to control bacterial growths in the open reservoirs. The frequent copper sulphate treatments may also have some effect on bacteria either directly or indirectly by reducing the available food supply.

The operation of the distribution reservoirs, as well as the operation of the filter plants, is a responsibility of the Sanitary and Pumping Section of the Distribution Division, Engineering Department. J. D. DeCosta is the Manager of the Distribution Division, and R. C. Kennedy is the Chief Engineer. L. J. Breuner is President of the Board of Directors of the East Bay Municipal Utility District, and J. W. McFarland is the General Manager.

Summary

It is believed the methods used by the District to control plankton and bacterial growths in open distribution reservoirs have been successful. Although some algae crustacea and bacteria have developed in these reservoirs, the regular chemical treatments and other control measures have kept the growths to a minimum and complaints from consumers have been eliminated.

Complete protection of drinking water can be accomplished only if the water is stored in adequately covered distribution reservoirs.

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